The Effect of Gentle Exercise Prior to a Cold Sensitivity Test used to Classify Non-Freezing Cold Injury

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ABSTRACT

A cold sensitivity test (CST) is one of the assessments used to classify the level of non-freezing cold injury (NFCI) in patients presented to a cold injury clinic. The CST involves sitting in a chamber at 30°C for at least 30 min then immersing the injured site (usually a foot) in water at 15°C for 2 min. The NFCI classification is based on the skin temperature before and 5 min after immersion. Previous studies have indicated that this test may not be very reproducible. In addition, a proportion of uninjured individuals are classified as having a NFCI if this test is used in isolation. The purpose of this study was to examine whether elevating deep body temperature slightly by gentle exercise prior to conducting a CST would increase the reproducibility of the test. Six male subjects with no history of NFCI undertook 10 CSTs with and without prior exercise (stepping, cycling and arm cranking). The results indicated that stepping for approximately 10 min to elevate deep body temperature by 0.3°C reduced the variability in response observed and produced more "normal" classifications compared to the control condition. An additional finding was that changes in skin temperature were not reflected in changes in blood flow measured using photoplethysmography. The implications of these findings are discussed.

1.0   INTRODUCTION

Non-freezing cold injury (NFCI) is a debilitating condition that can result in lifelong cold sensitivity, pain and sweating in the injured part, usually the feet. It is the most common form of non-combative related injury to afflict military forces and is common, at least in a mild form, in those participating in outdoor pursuits. A cold sensitivity test (CST) is one of the assessments used to classify non-freezing cold injury (NFCI)[1, 3]. This involves resting fully clothed in air at 30°C for at least 30 min, the injured area is then placed in a plastic bag and immersed in stirred water at 15°C for 2 min. Following removal from the water, the bag is removed and the patient rests for a further 5 min. Skin temperature (T_{sk}) is measured from infra-red thermal images of the injured area taken prior to immersion, immediately after, and 5 min after immersion. The degree of NFCI is determined from the temperature of the injured area immediately before immersion, and the amount of rewarming that occurs following removal from the water (Table 1). The assumption being that the higher the starting T_{sk} and the greater the amount of rewarming of T_{sk} following cooling, the less severe the cold sensitization/injury. It is further assumed that the increase in T_{sk} following cooling is indicative of a greater return of peripheral blood flow.

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE **01 MAY 2005**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **The Effect of Gentle Exercise Prior to a Cold Sensitivity Test used to Classify Non-Freezing Cold Injury**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Sport and Exercise Science Institute of Biomolecular Sciences University of Portsmouth Portsmouth, PO1 2DT UK**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **See also ADM001854, Prevention of Cold Injuries (Prevention des accidents dus au froid)., The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **UU**	18. NUMBER OF PAGES **6**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Table 1: Criteria used to classify the level of NFCI of the feet, based on the T_{sk} of the coldest toe pad.

T_{sk} at start	T_{sk} 5 min after immersion	Injury grading
> 32°C	> 32°C	Normal
> 32°C	30-32°C	Borderline
> 32°C	28-30°C	Mild
> 32°C	<28°C	Mild/moderate
< 32°C	28-32°C	Moderate
< 32°C	25-28°C	Moderate/severe
< 32°C	<25°C	Severe

Studies of the "normal" population have shown that there is wide variation in response to the CST, with a considerable proportion being classified as having a moderate/severe NFCI [2, 3]. The CST was also found to have a poor reproducibility [2]. Furthermore, the average response appears very similar to that of a non-perfused physical model, suggesting the changes in T_{sk} do not reflect blood flow [2]. One possible explanation for the poor reproducibility of the CST is that the resting period prior to immersion does not ensure all the subjects are fully vasodilated before testing. The hypothesis of this study was that increasing deep body temperature prior to the CST would improve its reproducibility.

2.0   METHODS

The experimental protocol was approved by the University of Portsmouth ethics committee. Six healthy male volunteers (mean (SD) age 35.5 (8.1) y; height 181.2 (4.1) cm; body mass 86.7 (12.3) kg), with no previous history of cold injury, peripheral vascular disease or diabetes participated in the study over the summer after giving informed written consent. All were non-smokers at the time of the trial and abstained from caffeine for 3 hours prior to testing.

T_{sk} was measured on the left great toe pad using a skin thermistor attached with a small piece of adhesive tape. T_{sk} was recorded prior to immersion, immediately after removal from the water and 5 and 10 min after immersion. Deep body temperature was measured using an aural thermistor (T_{au}) placed in the external auditory canal and insulated with neoprene. Temperatures were recorded every minute using a data logger (1200 series, Grants Instruments, Cambridge). Blood flow in the left great toe was measured using a photoplethysmograph (PPG 13, Medasonics, California) placed adjacent to the skin thermistor and recorded on a chart recorder (Model R12B, Medasonics, California) throughout the CST. The blood flow recorded prior to the CST was used as a baseline and measurements taken during the CST and the 10 min period afterwards were expressed as a percentage of this value. The position of the feet was kept constant except during the immersion phase of the CST when the left knee was bent and the foot lowered into water.

The subjects entered a climatic chamber at 30°C (mean temperatures (SD) at 0.95 m were: wet bulb 22.80 (0.50)°C; globe 31.04 (0.21)°C; dry bulb 31.09 (0.14)°C; at 0.05 m dry bulb 30.11 (0.13)°C, removed their socks and shoes and sat resting for 15 min while their aural temperature (T_{au}) equilibrated. Prior to the CST they either lay down resting for a further 15 min (control); lay resting covered with blankets for 20 min (blanket), or exercised at a comfortable, self-paced work rate until T_{au} increased by 0.3°C by stepping (22 cm step, average rate 15 steps.min^{-1}), cycling (average 50W) or arm cranking (average 15W). The subjects then rested in a recumbent position whilst baseline readings were taken. During the CST, their left foot was placed

in a plastic bag and immersed to the level of the mid-malleoli for 2 min in stirred water at 14.95 (0.02)°C. The foot was then removed from the water, the bag removed and the subject remained resting in a recumbent position for a further 10 min. During the CST the subjects were allowed to read but auditory stimuli were kept to a minimum. All subjects undertook each condition twice; the conditions were undertaken in a random order and separated by at least 4 hours.

Data are given as the arithmetic mean (SD). Data were analysed using a Wilcoxon Signed Ranks Test. The relationship between T_{sk} and blood flow was examined using Pearson's correlation. Statistical significance was taken as $P<0.05$.

3.0   RESULTS

The average exercise duration undertaken to increase T_{au} by 0.3°C was 9.5 (2) min for stepping, 10.6 (2.6) min for cycling and 12.7 (3.0) min for arm cranking. T_{au} during the CST was similar in the control and blanket conditions (37.04 [0.18]°C, n=24) and significantly higher in the exercise conditions (37.26 [0.18]°C, n=36). Within conditions, there was no difference in T_{au} between the first and second tests.
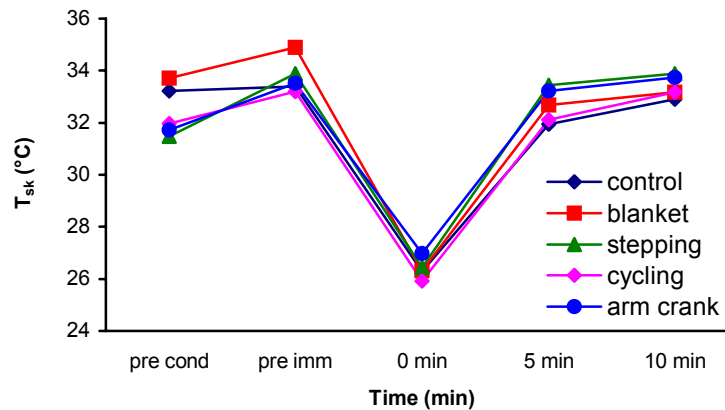

**Figure 1: Mean great toe T_{sk} during CST in the different conditions. Each data
point represents the mean of 12 observations (6 subjects, 2 tests).**

T_{sk} during the CST was similar prior to immersion and after 5 min in each condition (Figure 1). These T_{sk} responses were used to classify the level of NFCI based on the criteria shown in Table 1, the resultant classifications ranged from normal to moderate/severe. Between the different experimental conditions, 2 subjects had the same classification as a result of their CSTs. One subject varied by one classification, one by three classifications and the remaining 2 subjects varied by four classifications. The most consistent categorisation was seen with stepping. This condition also provided the greatest number of "normal" responses.

The variability in T_{sk} between the test-retest for each condition is shown in Figure 2. No significant differences were identified, with the exception of the finding that the variability in the stepping condition was less ($P<0.05$) than that seen in the control and blanket conditions pre-immersion.

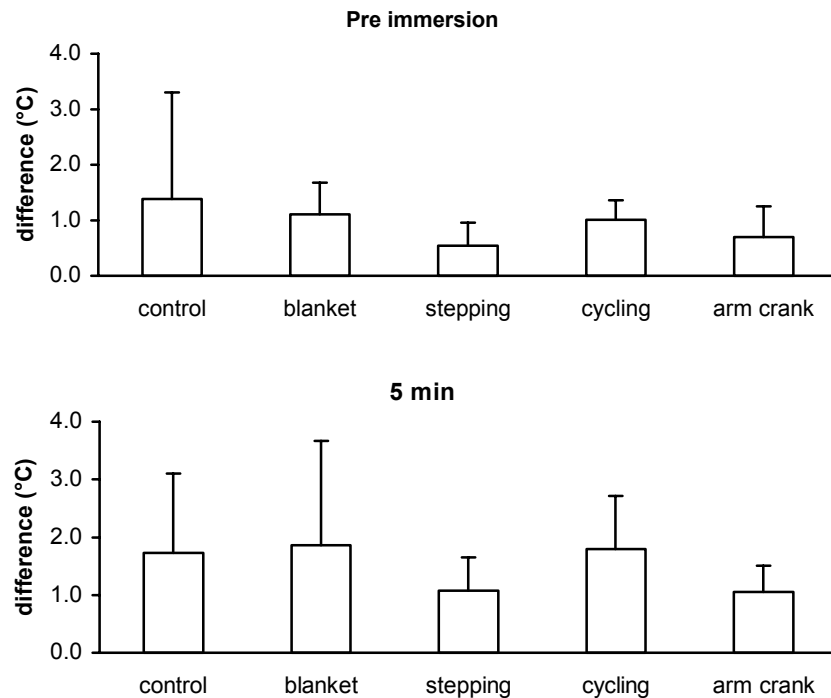The blood flow and T_{sk} in the 10 min after immersion were not linearly correlated.

Figure 2: Mean (SD) difference between the two CST in T_{sk} prior to
immersion and 5 min after immersion in each condition (n=6).

4.0   DISCUSSION

In this study, supposedly uninjured "normal" subjects were found to have a NFCI classification that ranged from "normal" to "moderate-severe". It is therefore concluded that mild to moderate NFCI is a fairly common condition[2]. As a consequence, a proportion of those individuals who enter the armed forces are likely to have an undetected, but classifiable, NFCI. The prevalence of mild to moderate NFCI raises the argument as to whether this mild form should be regarded as a normal rather than injured state.

To be a useful measure of injury and recovery, the CST should be as reproducible as possible with regard to the NFCI classification and discriminate between those that are injured and those that are not. Both the variability in the T_{sk} response immediately before the CST (pre-immersion), and the level of injury categorisation, were reduced by raising T_{au} by 0.3°C prior to testing, 10 minutes of stepping is a reasonable way of achieving this. Presumably, increasing deep body temperature a little completely removes any central vasoconstrictor input to peripheral blood flow and thereby negates this potential source of variability, leaving local factors (including degree of injury) to determine peripheral blood flow and temperatures. These findings need to be confirmed in patients with NFCI. As can be seen from Table 1, pre-immersion T_{sk} is important, as a temperature of less than 32°C at this time results in a categorisation of, at best, "moderate" NFCI. The lack of an effect of prior exercise on the variation in the test results observed 5 min post-immersion, suggests that the

permissive influence of deep body temperature has been lost by this time as deep body temperature returned towards normal.

The lack of a linear relationship between T_{sk} and blood flow suggests that the changes in T_{sk} during the CST may be independent of skin blood flow as measured by photoplethysmography. The photoplethysmographic technique tends to be sensitive to changes in venous capacitance as well as blood flow. Thus, changes in venous capacitance following exercise and immersion may have been confounding the blood flow measures in this study. Additionally, a number of factors associated with the distribution of blood flow and heat loss to the environment mean that blood flow and T_{sk} would not necessarily be linearly correlated in the dynamic situation of a CST. Alternatively, the increase in T_{sk} observed after immersion may result from passive warming by the environment. This conclusion is supported by the results of the earlier study in which a non-vascular model was found to respond in a very similar manner to a "normal" toe[2]. More detail vascular studies using additional blood flow assessments and larger subject numbers are required to settle these issues.

5.0   REFERENCES

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6.0   ACKNOWLEDGEMENTS